

Ambulatory monitoring of pulmonary artery pressure

A preliminary clinical evaluation

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SUMMARY Traditional measurement and recording methods are inadequate for continuous monitoring of ambulatory pulmonary artery pressure. Therefore a new miniaturised solid state system has been developed and assessed. A manometer tipped catheter, inserted via a subclavian or cephalic vein, was used together with an isolated amplifier and peak detectors to determine systolic and diastolic pressures. Pressures were averaged over 30 seconds and stored in digital memory. After a 24 hour recording period data were rapidly transferred to a microcomputer for numerical or graphical display.

Thirteen patients had continuous ambulatory monitoring performed for between 24 and 96 hours, in seven to evaluate symptoms of dyspnoea in subjects with valvular or coronary disease (group 1), and in six to achieve optimal oral treatment for left heart failure (group 2). The catheter was calibrated before insertion and was rechecked after removal. There was less than 1% zero level drift and similar gain stability. Systolic pressures ranged from 10 to 97 (mean 39.5) mmHg, and diastolic from 1 to 46 (mean 15.3) mmHg. Four patients in group 1 had symptoms of dyspnoea associated with normal pressures, while three had raised pressures. Four of the six patients monitored in group 2 had major alterations in their treatment based on data obtained during monitoring. There were no complications.

This system, which allows safe, reliable, and prolonged recording of ambulatory pulmonary artery pressure, represents a considerable advance in the ability to assess the cause of dyspnoea and to manage left heart failure.

Measurement of pulmonary artery pressure provides valuable diagnostic information when used in a variety of clinical situations. Hellems *et al.*¹ and Lagerlöf and Werkö² described the use of the pulmonary artery wedge pressure measured during right heart catheterisation in order to estimate left ventricular filling pressure. Swan *et al.*³ with their balloon tipped flow guided catheter provided an impetus for prolonged bedside monitoring of pulmonary arterial and pulmonary artery wedge pressure. Several workers have shown that pulmonary artery end-diastolic pressure approximates to the wedge pressure, allowing even simpler prolonged monitoring.⁴⁻⁶ Measurement of the pulmonary artery systolic pressure is also valu-

able, especially in patients with pulmonary arterial hypertension.⁷ Conventionally, monitoring is a "bed-side" procedure and does not allow evaluation of ambulant patients.⁸⁻¹⁰ To overcome this limitation, a miniature solid state system has been developed for ambulatory pulmonary artery pressure monitoring. The present study was performed to evaluate it in a clinical setting.

Patients and methods

Thirteen adults were selected for monitoring. There were two women and 11 men, aged 44 to 66 (mean 54) years. Seven were selected to evaluate symptoms of dyspnoea in patients with valvular or coronary heart disease (group 1) and six to optimise oral treatment for left heart failure (group 2). Recordings were made for between one and four consecutive 24 hour periods as indicated clinically. The clinical details of the patients are shown in Table 1.

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Table 1 Clinical details of patients

Case No.	Sex	Age (y)	Diagnosis	Reason for study	Route of insertion	Number of periods recorded
1	M	53	CAD	Evaluate dyspnoea	R arm	1
2	M	61	CAD	Evaluate dyspnoea	R arm	1
3	M	44	CAD	Evaluate dyspnoea	R arm	2
4	F	53	CM	Optimise treatment	R subclavian	1
5	M	52	CAD	Evaluate dyspnoea	R subclavian	2
6	M	60	AR	Evaluate dyspnoea	R arm	2
7	M	66	CAD	Optimise treatment	R arm	1
8	M	60	MR	Optimise treatment	R arm	1
9	M	52	CAD	Evaluate dyspnoea	R arm	1
10	M	48	AS	Optimise treatment	R arm	1
11	M	51	CAD	Optimise treatment	R subclavian	4
12	F	47	AR, MS	Evaluate dyspnoea	R arm	1
13	M	49	CAD LV aneurysm	Optimise treatment	L subclavian	1

AR, aortic regurgitation; AS, aortic stenosis; CAD, coronary artery disease; CM, cardiomyopathy; LV, left ventricular; MR, mitral regurgitation; MS, mitral stenosis.

CATHETER

A miniature strain gauge transducer, 10 mm long and 2 mm in diameter, mounted on the end of a standard polyurethane 6F NIH type catheter* was used for pressure measurement. To equilibrate the transducer, and in particular the silicon rubber membrane covering the strain gauge, the catheter was immersed in sterile saline for at least five hours before use. Immediately before insertion the catheter was calibrated using a mercury column and the calibration was rechecked after the catheter was removed. The catheter was introduced via an antecubital vein in nine patients and through a subclavian vein by supraclavicular puncture in the remainder.

After catheter insertion patients were encouraged to undertake normal activities, and were each provided with a diary to log their activities and symptoms.

RECORDER

The transducers were driven and demodulated by an electrically isolated preamplifier. The full range of the system was set at -10 to 100 mmHg. The pressure signal was filtered and passed to analogue "peak" detectors, which were used to determine the systolic and diastolic values. These values were each averaged over 30 second periods and then the signal converted into digital form by an analogue to digital converter. The processed signals were then written into 8 Kbytes of semiconductor memory giving a maximum recording time of 33 hours. There was an event marker that was operated by the patient. Recording, playback, or holding modes were selected using a keyswitch. The unit measures 23×22×9 cm and weighs 1.5 kg.

DATA RETRIEVAL AND DISPLAY

After a full recording (usually for 24 hours) the recorder was detached and the keyswitch placed in the

holding mode. The stored data were then transferred on to a small computer. Transfer took approximately 60 seconds, and the data were set out and printed numerically and graphically. A full 24 hour graphical display was usually used, but an expanded mode was available to examine details. In addition, data were permanently stored on floppy diskettes.

Results

Nineteen recordings were obtained from 13 patients. The maximum, minimum, and average systolic and diastolic pressures for each recording period are shown in Table 2. The maximum systolic pressure recorded was 97 mmHg, and the minimum was 10 mmHg, with a mean of 39.5 mmHg. The maximum diastolic pressure was 46 mmHg, the minimum was 1 mmHg, and the mean was 15.3 mmHg. Recordings were taken for exactly 24 hours, thus giving a theoretical total of 5760 stored values. The maximum number of actual values was 5761 with a minimum of 5756, thus giving a temporal stability of better than 0.1%. Disregarding obvious sudden drift after four hours in case 7 (the rest of this recording was ignored), there was less than 1% zero level drift and there was also better than 1% gain stability.

In the seven group 1 patients, three (cases 2, 6, and 9) had pressures that were never sufficiently raised to account for the dyspnoea (Fig. 1). Cases 1, 3, and 12 had episodes of dyspnoea correlating with raised pulmonary artery diastolic pressures which therefore almost certainly accounted for the patients' symptoms (Fig. 2). Case 5, a man with symptoms of severe exertional dyspnoea two weeks after coronary artery bypass surgery, had a normal clinical examination, unremarkable lung function studies, and a normal chest x-ray film. During ambulatory pulmonary pressure monitoring, though he had a maximum diastolic pressure of 20 mmHg, the average diastolic value was

*Gaeltec Limited, Isle of Skye, Scotland.

Table 2 Pressures (mmHg) during each 24 hour period of pulmonary artery monitoring.

Case No.	Systolic			Diastolic		
	Minimum	Maximum	Average	Minimum	Maximum	Average
1	15	61	32	3	24	13
2	17	37	26	2	11	5
3	20	53	30	5	27	18
4	24	46	31	10	26	18
5	10	60	26	2	13	6
6	22	55	38	5	20	14
7	10	54	22	3	14	7
8	16	67	30	1	12	6
9	17	56	32	3	16	9
10	22	30	25	7	11	8
11	17	63	34	6	20	10
12	15	36	24	6	17	10
13	24	69	39	10	32	17
14	50	97	74	19	42	29
15	43	97	74	16	42	30
16	40	96	71	17	44	28
17	36	96	67	14	37	24
18	20	51	35	11	31	19
19	27	59	40	10	30	20
Mean	23.4	62.3	39.5	7.9	24.7	15.3

10.5 mmHg over the two days of monitoring and his symptoms of dyspnoea did not correspond with even the slightly raised values. After strong reassurance the patient's symptoms resolved.

In the six group 2 patients, two (cases 4 and 7), who were scheduled for vasodilator treatment for left heart failure, were found to have satisfactory pressures on their existing diuretic therapy alone. Case 8, a man

with mitral regurgitation, had been recommended to take large doses of diuretics by his referring physician, but both his formal catheter laboratory studies and ambulatory pulmonary artery pressure studies showed that no treatment was necessary. Case 10, a man with aortic valve stenosis, was monitored in order to improve his drug regimen for left ventricular failure before cardiac surgery and case 13 was monitored while taking large doses of frusemide and isosorbide dinitrate (as a vasodilator) before deciding whether surgery should be undertaken in order to resect a left ventricular aneurysm. Case 11 was monitored for four days while receiving digoxin, frusemide, and isosorbide dinitrate, and small, but clinically significant, falls in systolic and diastolic pressures were documented.

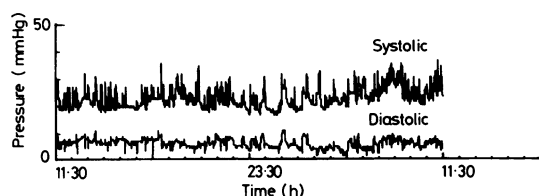


Fig. 1 Pulmonary artery pressure plot over 24 hours from a patient with normal pressures (case 2).

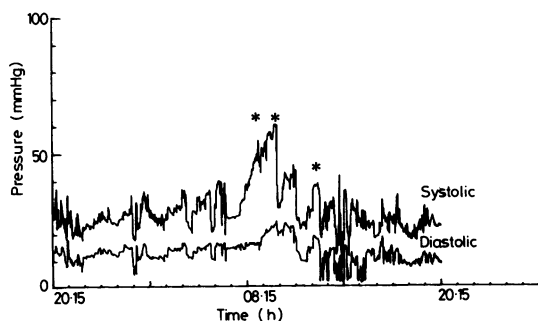


Fig. 2 Pulmonary artery pressures in a patient with raised values correlating with dyspnoea as noted in his diary (marked *). Three episodes of exertional dyspnoea were noted, all occurring in the morning (case 1).

Discussion

Until the modification by Courmand and Ranges¹¹ of Forssmann's techniques of venous catheterisation,¹² there was no simple method for studying pulmonary haemodynamics in man. Since these early studies there have been many reports of the value of pulmonary artery pressure measurement and monitoring in a variety of disease states.^{4,6,13} In the absence of pulmonary vascular disease, the pulmonary artery end-diastolic pressure correlates well with the left ventricular filling pressure (left ventricular end-diastolic pressure) over a very wide range of pressures.^{10,14,15}

Pulmonary artery pressure measurement enables the diagnoses of left heart failure and pulmonary hypertension to be established and quantified, and continuous monitoring allows medical treatment to be precisely tailored for each patient. Such patients,

however, are usually most symptomatic when ambulatory, and conventional bedside techniques allow for only the measurement of resting haemodynamics, occasionally aided by the performance of a simple exercise test. In addition, there are many patients who complain of dyspnoea on exertion, with normal resting pressures, in whom monitoring in an ambulatory setting could add much useful data.

To assess these problems a system for measuring, recording, and displaying ambulatory pulmonary artery pressures has been developed. Ambulatory pressure monitoring (usually of systemic arterial pressures) has previously been achieved using fluid filled luminal catheters with small battery powered cassette recorders, such as the Oxford recorder,¹⁶⁻¹⁸ or by using similar catheters attached to radiotelemetry equipment.^{19,20} Fluid filled catheters require a relatively bulky perfusion unit and are subject to blockage, leakage, have a poor frequency response, and are liable to artefacts such as overshoot, overdamping, and catheter whip.²¹ In addition, maintaining a stable zero reference point for the external transducer is difficult in ambulatory patients because of the variations imposed by changes in posture.²² External transducers and cassette recorders are also subject to large changes in environmental temperature and this may cause considerable drift.²³ Cassette recorders are liable to variations of recording speed which can introduce errors²³ that may be acceptable when recording relatively high pressures such as those of the systemic circulation, but that are unacceptable for the lower pressure pulmonary circulation. Radiotelemetry limits the patient to the hospital environment or to close proximity to a dedicated radio receiver.^{20,24}

The recording system employed in this study avoids the problems of fluid filled catheters and allows a stable zero reference with changes of posture. The catheters are expensive, however, and are therefore not disposable and require careful handling and calibration. In addition, several catheters have become unstable because of defects in the silicon membrane and have had to be returned for repair. Steps are being taken to overcome this in a new design of catheter. The digital system circumvents the deficiencies of small cassette recorders and also of radiotelemetry systems, though a recording of the analogue pulse waveform is not obtained with the present device.

This paper is a preliminary report of the use of this form of monitoring for patient management. The system is now being refined and modified, for investigation of normal physiological variation, the natural progress of disease processes, the effects of drugs on pulmonary artery pressures, and the relation of ambulatory haemodynamic data to symptomatology.

A new recorder is being designed using a micro-processor as a central processor with plug-in modules supplying the controlling software. This will allow a reduction in size (by approximately 50%), with longer recording times and shorter sampling intervals. Other variables, for example heart rate, will be recorded and such a system will be more versatile.

Ambulatory monitoring of the pulmonary pressure has the potential of increasing the value of haemodynamic monitoring in much the same way as ambulatory electrographic monitoring has improved our understanding and management of arrhythmias.

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